SIMULATIONS OF NOISE-PARAMETER VERIFICATION USING CASCADE WITH ISOLATOR OR MISMATCHED TRANSMISSION LINE

James Randa[1], Ken Wong[2], Roger Pollard[2,3]

[1]Electromagnetics Division, NIST, Boulder, CO
[2]Agilent Technologies, Inc., Santa Rosa, CA
[3]School of Electronic and Electrical Engineering, University of Leeds, Leeds, UK

Agilent Technologies

UNIVERSITY OF LEEDS

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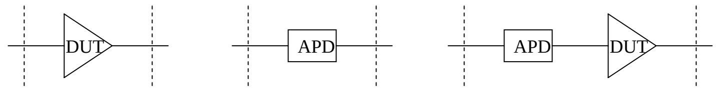
I. INTRODUCTION

- Noise-parameter measurements are moderately complicated & can be difficult, especially for low-noise and/or poorly matched amplifiers or transistors. Need verification method(s) to check that measurements are correct.

- Would like a method that tests ability to measure devices that are *active* and possible *poorly matched*. Would also be nice to have a method that could be implemented in an on-wafer environment.

- ❑ Suggested method:



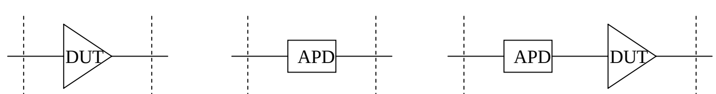
(a) (b) (c)

Measure (a), measure (b), predict (c), measure (c), compare.
Must have uncertainties for both measurements & predictions.

- ❑ Will present results of simulations implementing the method, including uncertainties.

II. THEORY & SIMULATION

- ❑ Process to be simulated:
  - Measure S-parameters of passive device & amplifier (don't need to sim; just choose values & use VNA uncertainties).
  - Measure noise parameters of amplifier
  - Predict noise parameters of tandem configuration
  - Measure noise parameters of tandem config.
  - Compare prediction & "measurement."



(a) (b) (c)

- The simulator:
  - Was developed for the Monte Carlo uncertainty analysis for NIST noise-parameter measurements.
  - Each individual measurement (all S-parameters, reflection coefficients, input & output noise temperatures) is simulated by randomly choosing a value from the distribution around the "true" value, with the standard deviation of the distribution given by the standard uncertainty.

- The simulator (cont'd):
  - For the "true" values, use measured values for two different amplifiers (8 – 12 GHz)
    - Agilent amp: $F_0 \approx 2.5$ to 3 dB, $G \approx 14.5$ dB
    - NIST LNA: $F_0 \approx 1.5$ dB, $G \approx 33$ dB
  - NIST measurement & analysis methods are assumed:
    - multiple (near-) ambient input terminations, one hot input termination
    - measure output noise temperatures
    - analysis in terms of elements of the noise correlation matrix in the wave representation:

$$k_B X_1 \equiv \left\langle |c_1|^2 \right\rangle,\; k_B X_2 \equiv \left\langle |c_2 / S_{21}|^2 \right\rangle,\; k_B X_{12} \equiv \left\langle c_1 (c_2 / S_{21})^* \right\rangle$$

- The simulator (cont'd):
  - Results for X's are converted to IEEE noise parameters.
  - So, simulate measurement, analyze, repeat. 40,000 times.
- Uncertainties
  - Measurement uncertainties
    - Type-B: $u_B(X)$ = std dev of distribution of simulated measurement results for X
    - Type-A: the fit to each simulated measurement set returns the fitting parameters (X's) and the covariance matrix, V_{ij} . For the sim, we use $u_A = \sqrt{\langle V_{ii} \rangle}$, where avg is over all the sims.

- Uncertainties (cont'd)
  - Prediction uncertainties: normal propagation of uncertainties

$$X_i' = f_i(\boldsymbol{X}, \boldsymbol{S}, \boldsymbol{S_{APD}}) \qquad u_c^2(X_i') = \sum_{j,k} \frac{\partial f_i}{\partial x_j} \frac{\partial f_i}{\partial x_k} u(x_j, x_k)$$

For example,

$$X_2' = \frac{1}{G'}\left[\left|S_{22}^P\right|^2 X_1 + \left|1 - S_{11}^A S_{22}^P\right|^2 X_2 + 2\,\mathrm{Re}\left[S_{22}^P\left(1 - S_{11}^A S_{22}^P\right) X_{12}\right] + T^P\left(1 - \left|S_{22}^P\right|^2 - \left|S_{21}^P\right|^2\right)\right] = F_0'$$

so need partials of X_2' with respect to X_1, X_2, Re & Im X_{12}, G_0, Re & Im $S_{11}{}^A$, Re & Im $S_{21}{}^P$, and Re & Im $S_{22}{}^P$. Straightforward, but tedious.

- Uncertainties (cont'd)
  - To get uncertainties in predictions for IEEE parameters, do another propagation of uncertainties:

$$u_A(I_i) = \sqrt{V_{ii}(IEEE)}\ ,$$

$$V_{ij}(IEEE) = \sum_{i',j'=1}^{5} \frac{\partial I_i}{\partial X_{i'}} \frac{\partial I_j}{\partial X_{j'}} V_{i'j'}(X)\ .$$

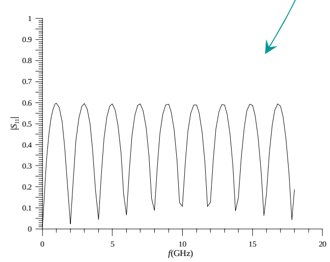
For example,

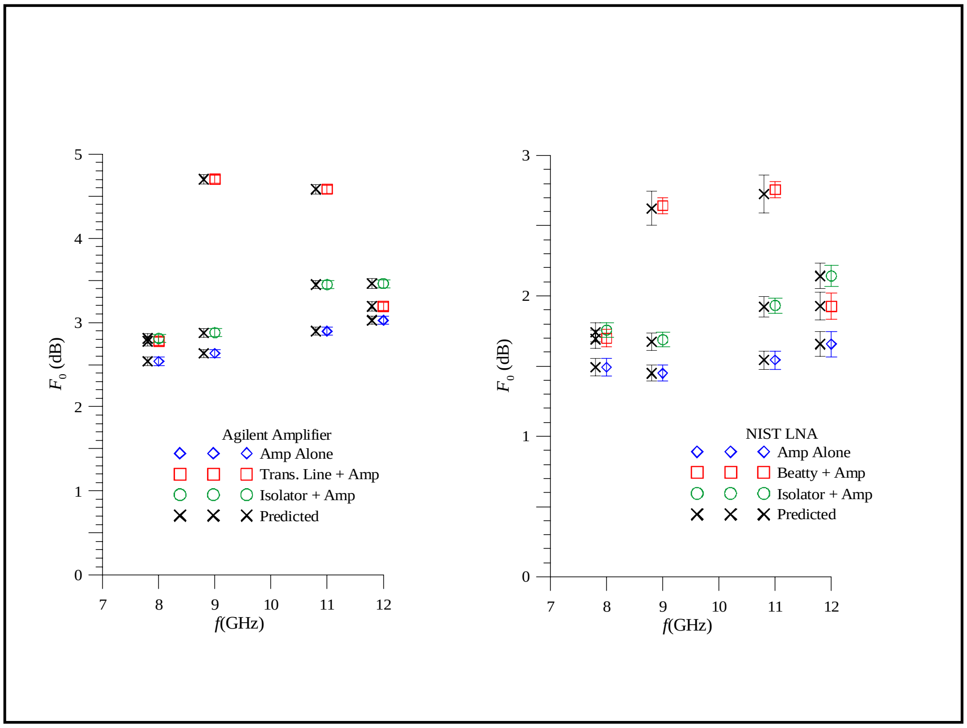
$$T_{\min}{}' = \frac{X_2{}' - \left|\Gamma_{opt}{}'\right|^2 \left[X_1{}' + \left|S_{11}{}'\right|^2 X_2{}' - 2\,\mathrm{Re}\left(S_{11}'^{*} X_{12}{}'\right) \right]}{\left(1 + \left|\Gamma_{opt}{}'\right|^2\right)}$$

etc.

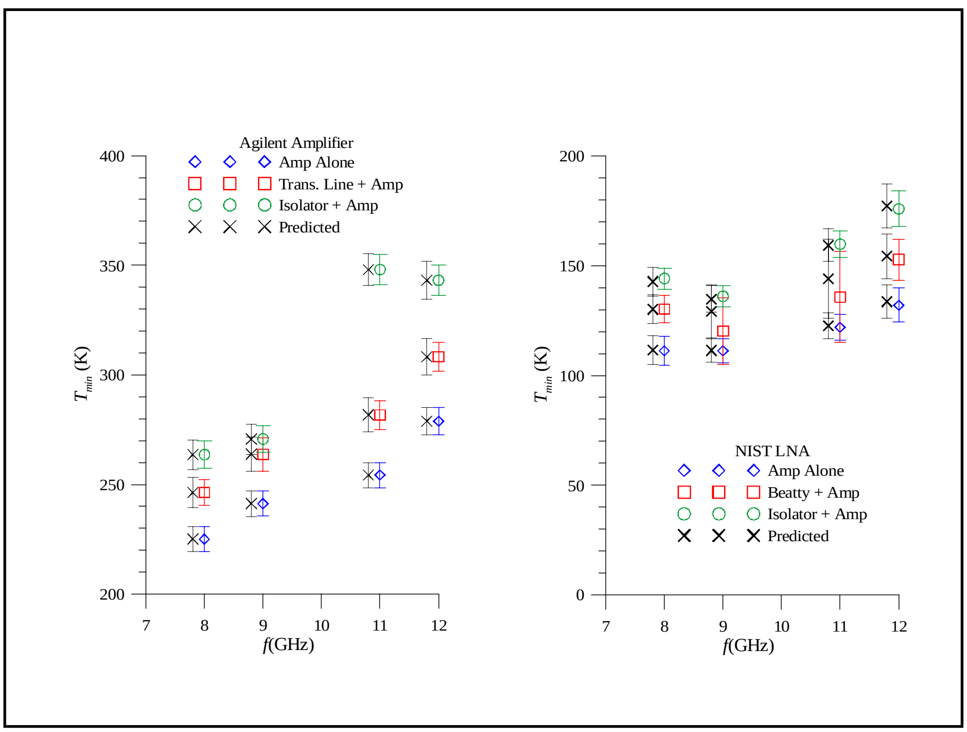
III. RESULTS

- Graphs compare predictions (based on sim of measurements of amp alone & passive device alone) to measurement sims for the tandem configuration.
- Show for mismatched transmission line (Beatty std) and isolator (nominally 20 dB) as passive device.
- Also show amp alone. (Pred. is true value.)

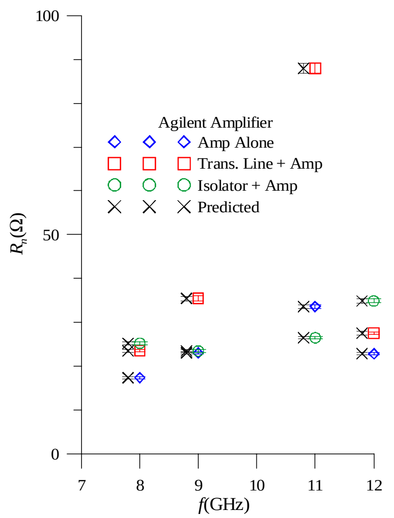


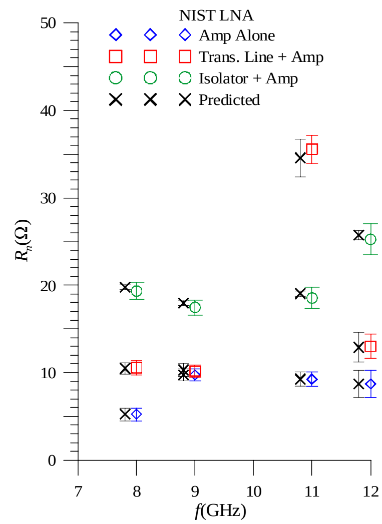


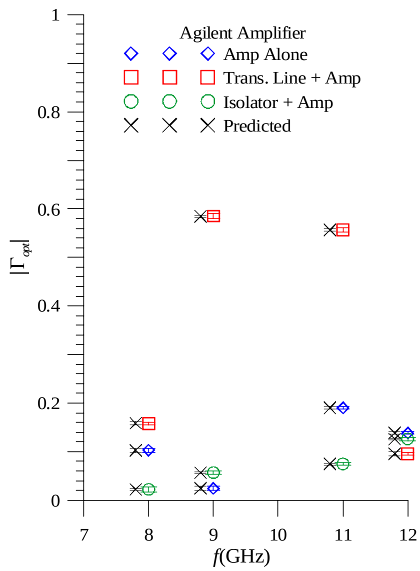
Agilent Amplifier
Amp Alone
Trans. Line + Amp
Isolator + Amp
Predicted
NIST LNA
Amp Alone
Beatty + Amp
Isolator + Amp
Predicted
F_0 (dB)
f(GHz)

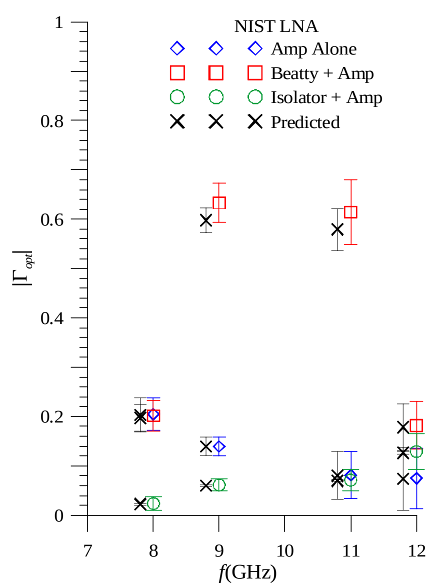


Agilent Amplifier
Amp Alone
Trans. Line + Amp
Isolator + Amp
Predicted
NIST LNA
Amp Alone
Beatty + Amp
Isolator + Amp
Predicted
T_{min} (K)
f(GHz)


Agilent Amplifier
Amp Alone
Trans. Line + Amp
Isolator + Amp
Predicted
$R_n(\Omega)$
f(GHz)

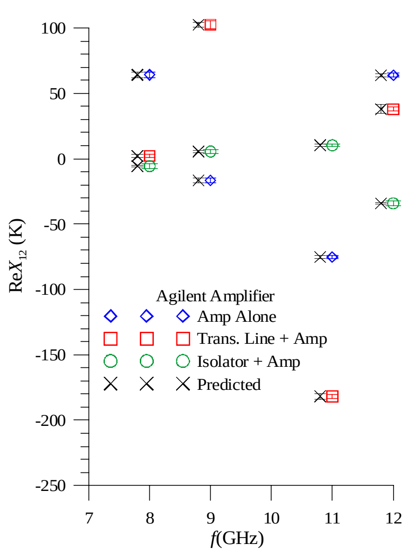

NIST LNA
Amp Alone
Trans. Line + Amp
Isolator + Amp
Predicted
$R_n(\Omega)$
f(GHz)

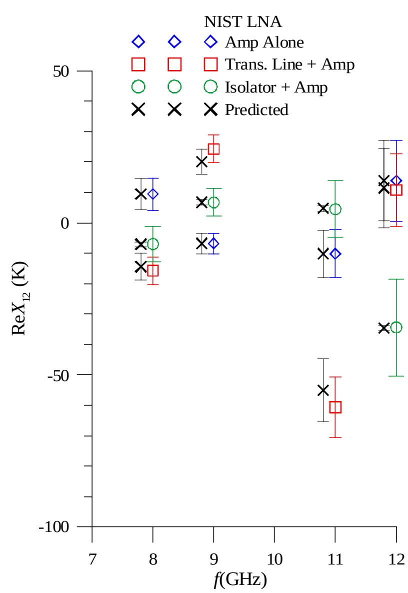

Agilent Amplifier
Amp Alone
Trans. Line + Amp
Isolator + Amp
Predicted
$|\Gamma_{opt}|$
f(GHz)

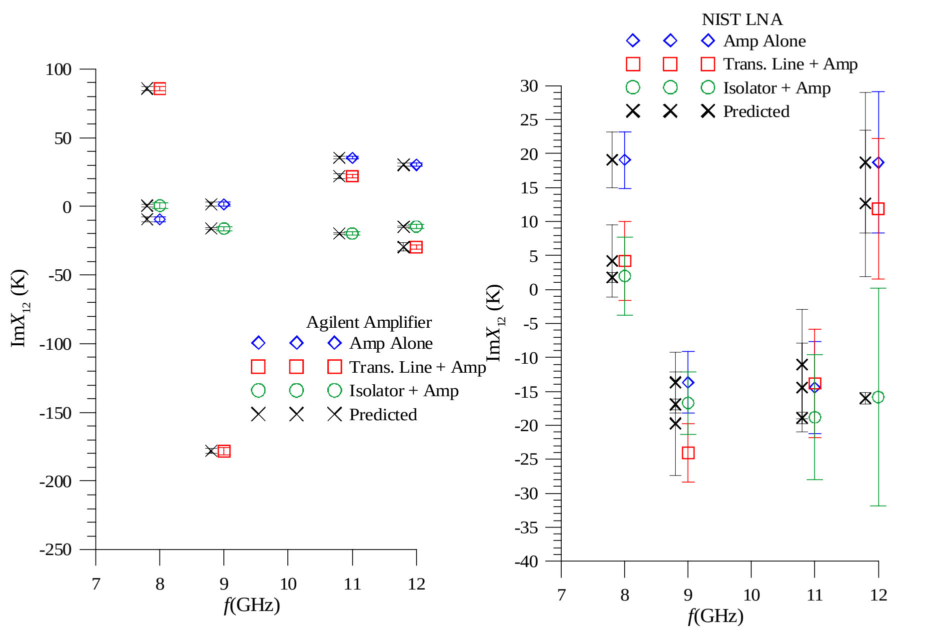

NIST LNA
Amp Alone
Beatty + Amp
Isolator + Amp
Predicted
$|\Gamma_{opt}|$
f(GHz)

- The isolator provides an (approximate) absolute verification standard because some noise properties (such as X_{12}) of the tandem configuration are calculable from just the S-parameters of the amplifier and isolator.

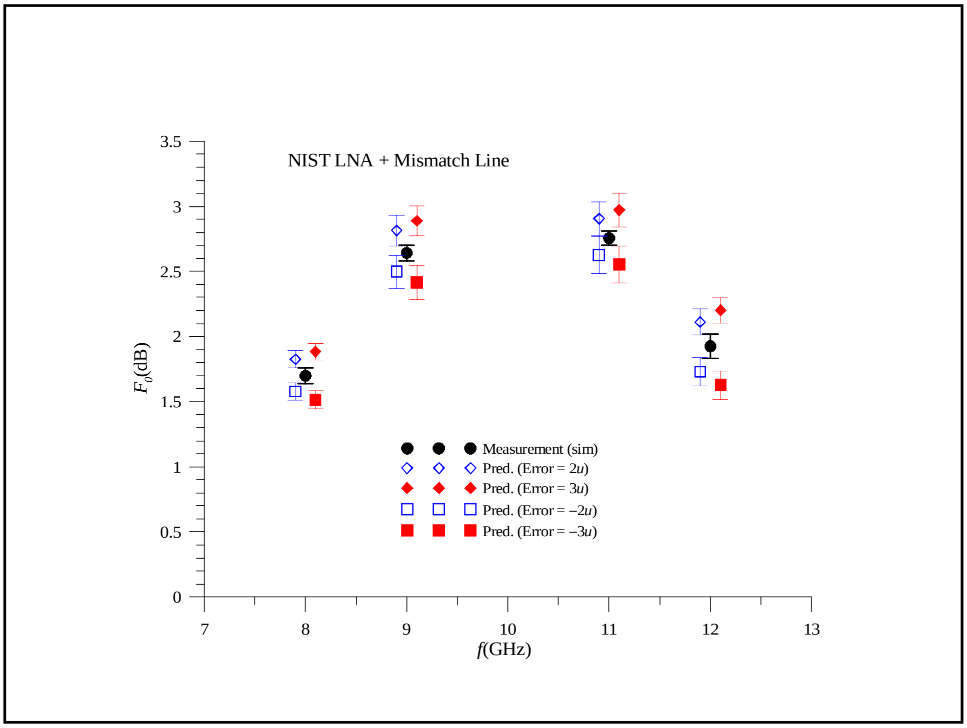
$$k_B X_{12} \equiv \left\langle c_1 (c_2 / S_{21})^* \right\rangle$$

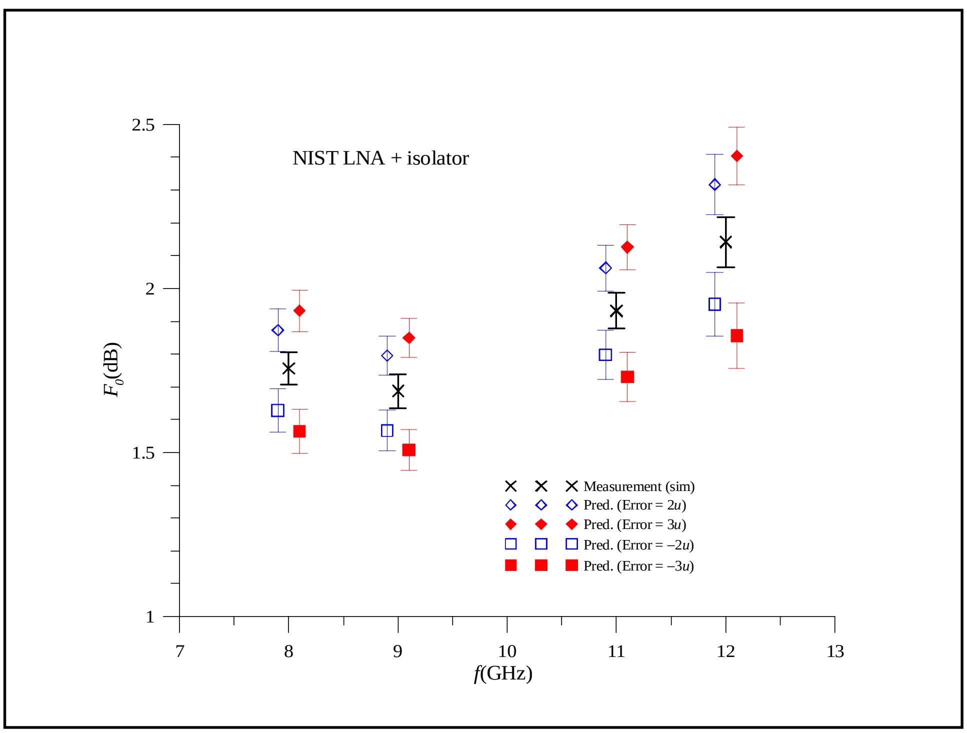






- Preceding graphs showed that the predictions “should” agree with measurements if no mistakes. But does the verification method catch mistakes? (more work to do on this, but have some simple results)


NIST LNA + Mismatch Line
Measurement (sim)
Pred. (Error = 2u)
Pred. (Error = 3u)
Pred. (Error = −2u)
Pred. (Error = −3u)
F0(dB)
f(GHz)


NIST LNA + isolator
Measurement (sim)
Pred. (Error = 2u)
Pred. (Error = 3u)
Pred. (Error = −2u)
Pred. (Error = −3u)
F0(dB)
f(GHz)

IV. DISCUSSION & CONCLUSIONS

- Simulations indicate that method should be effective.
- Tradeoffs:
  - Mismatched line provides a test on a poorly matched device.
  - Isolator provides an “absolute” verification standard.
  - Mismatched line can be implemented in an on-wafer environment (as could an attenuator).

- Next steps:
  - More sophisticated treatment of tests of error catching.
  - Measurements.

Contact Information:

Jim Randa

randa@boulder.nist.gov
(+1) 303-497-3150

http://boulder.nist.gov/div818/81801/Noise/index.html